SUBSOILING AND K PLACEMENT: EFFECTS ON COTTON WATER RELATIONS

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Abstract

Deep placement of K fertilizer has been suggested as a means of alleviating late season K deficiency on soils testing adequate in surface-soil K but with a low level of K in the subsoil. However, the comparative and interrelational effects of deep tillage and K fertilizer placement have not been elucidated. This field study evaluated the relative effects of deep tillage (subsoiling) and K fertilizer placement on yield, leaf K deficiency symptoms, soil water depletion, and stomatal conductance of cotton grown on a soil with a root-restricting hardpan. The study was conducted for two years (1990-91) on a Norfolk sandy loam (fine loamy, thermic siliceous Typic Kandiudults) in east-central Alabama. Treatments selected for study from a randomized complete block of four replications were: 1) no-K, no-subsoiling; 2) no-K, in-row subsoiled; 3) surface application of 75 lb K/acre without subsoiling; 4) surface application of 75 lb K/acre plus in-row subsoiling; and 5) deep placement of 75 lb K/acre in the in-row subsoiled channel. Deep placement of K fertilizer resulted in the greatest soil water depletion below the 8-inch depth while surface K application without subsoiling resulted in the least soil water depletion below the 8-inch depth. Stomatal conductance both years was highest in the no-K nonsubsoiled treatment and lowest where K fertilizer was applied in conjunction with subsoiling. There were no indications of stress-induced stomatal closure and stomatal closure was not related to severity of leaf K deficiency symptoms. Leaf K concentrations at early bloom were increased by K application and reduced by subsoiling. Subsoiling and surface application of K resulted in the greatest seed cotton yield, highest leaf K concentration at early bloom, greatest leaf area, and lowest stomatal conductance. Our results suggest that stomatal closure and premature leaf senescence is not the most likely mechanism for the appearance of leaf K deficiency symptoms. Although subsoiling is necessary on Coastal Plain soils with root-restricting hardpans, surface application of K fertilizer was superior to deep placement of K on these soils.

Introduction

Potassium deficiencies have been cited as being responsible for yield reductions averaging 15 to 20% in the San Joaquin Valley of California (Cassman et al., 1989) and are also a concern in the Southeast (Maples et al., 1989; Ebelhar, 1991). The increased occurrence of K deficiency symptoms in cotton has been attributed in part to improved earlier and higher yielding cultivars (Maples et al., 1989; Ebelhar, 1991), however, the problem has been a concern since at least 1932 (Sawhney, 1932).

Many soils in the Southeast where cotton is grown have medium to low soil test ratings for K in the subsoil (Tupper et al., 1989; Mitchell et al., 1992); late season K deficiency can occur where surface soil is not considered K deficient but where subsoil K is low. Poor root distribution in surface soil layers adequate in K, due to sensitivity to low soil water potential, has been linked to poor K nutrition in cotton when subsoil K is low (Gulick et al., 1989). Subsoil K fertilization has been recommended as a means of alleviating late season K deficiencies (Tupper et al., 1988; 1989). Results from deep placement of K fertilizer studies have been contradictory, however, and in many instances the effect of subsoiling per se has been confounded by K placement effects (Tupper et al., 1992a; 1992b).

Alleviation of soil compaction by deep tillage can affect K uptake due to improved root growth. Increased root exploitation of the soil would improve K uptake since diffusion to root surfaces is the primary mechanism responsible for K^+ uptake (Barber, 1984). Soil compaction is one of several plant stresses that have been linked to the K deficiency syndrome (Combrink, 1988). The number and distribution of roots, as well as the amount and distribution of available K, affect both plant demand and uptake of water and K^+ by cotton.

Potassium deficiency and water stress are both known to reduce stomatal opening (Peaslee and Moss, 1966; Hsiao, 1973; Hsiao, 1975; Nagarajah, 1979). Stomatal closure and accompanying premature leaf senescence has been hypothesized as the mechanism for the characteristic leaf deficiency symptoms associated with late season K deficiency in cotton (Combrink, 1988). To date, there have been no studies to determine the comparative effects of subsoiling vs. K fertilizer placement on water relations of cotton relative to occurrence of late season K deficiency syndrome.

The purpose of this study was to determine the relative effects of deep tillage (subsoiling) and K fertilizer placement on yield, severity of K deficiency symptoms, soil water depletion, and stomatal conductance of cotton grown on a soil with a root-restricting hardpan.

Materials and Methods

Data for this study were collected in 1990 and 1991 from selected treatments of a larger study initiated in 1989 on a Norfolk fine sandy loam in east-central Alabama. The site had a well developed 5- to 7-inch thick hardpan beginning at 6- to 8-inches. The soil had a medium soil test rating for K in the top 6-inches (90 lb K/acre) and a low soil test rating at greater depths (68 to 84 lb K/acre).

A description of the larger study and yield data from 1989 are reported by Mullins et al. (1991). Five treatments were selected for evaluation in order to determine the role of subsoiling and K fertilizer placement on cotton water use, stomatal conductance, plant growth, appearance of K deficiency symptoms, and seed cotton yield. The five treatments from which data were collected included: i) a no-K, no-subsoiling check; ii) a no-K, in-row subsoiled check; iii) surface application of 75 lb K/acre without in-row subsoiling; iv) surface application of 75 lb K/acre plus in-row subsoiling; and v) deep placement of 75 lb K/acre in the in-row subsoiled channel. All treatments were applied annually in the same plots each year. Subsoiling depth was 15-inches. Deep placement of fertilizer (muriate of potash) and subsoiling were accomplished using a two-row deep fertilizer applicator described by Tupper and Pringle (1986). The applicator has twin parabolic shanks with rectangular steel tubes welded to the back of each shank. Each tube had deflector plates designed to distribute the fertilizer in the subsoil channel at the 6- to 15-inch depth. Treatments were applied 5 days before planting in 1990 and 4 days before planting in 1991.

'Deltapine 50' cotton was seeded at 66,000 seed/acre in 40-inch rows on 30 April in 1990 and on 22 April in 1991. Individual plots were four rows, 20-ft long. The five treatments selected for study were included in a set of 14 treatments arranged in a randomized block with four replications.

In 1990 and 1991, parallel-paired stainless steel rods (0.25-inches diameter) were installed in the row at three depths (8, 16, and 32 inches). A Tektronix® 1502B cable tester was used to measure soil water using the time-domain reflectometry method (TDR) as developed by Topp (Topp et al., 1980; Topp and Davis, 1985). In 1990, measurements were taken six times, beginning on 21 August and ending 11 September. This corresponded to the period 113 to 134 days after planting (DAP). Peak bloom occurred approximately 18 days before measurements were initiated in 1990. In 1991, measurements were taken 12 times beginning 22 July and ending 5 September. This corresponded to the period 90 to 135 DAP. Peak bloom was approximately 6 days after initiation of measurements in 1991.

In 1990 and 1991, leaf stomatal conductance was measured with a LI-1600 steady state porometer (LI-COR® Inc., Lincoln, NE) from the abaxial side of unshaded, uppermost fully expanded leaves in the canopy . Measurements were made from single leaves from ten individual plants from the middle two rows of each plot. Measurements were made three times from 24 August (116 DAP) to 11 September (134 DAP) in 1990 and six times from 29 July (96 DAP) to 5 September (135 DAP) in 1991.

Soil penetrometer recordings were made in 1991 28 DAP. Measurements were made using a hand-held Bush® recording penetrometer (Mark 1 Model 1979; Findlay, Irvine Ltd., Penicuik, Scotland). The readings were taken when the soil water content was near field capacity, after a heavy rain (0.96 inches). Five penetrations to a depth of 20-inches were made at five positions within subsoiled and nonsubsoiled check (no-K applied) plots. The positions were: 0, 5, 10, 15, and 20 inches away from the in-row position. Complete penetrometer data has been presented elsewhere (Mullins et al., 1992). Data from the in-row position only is presented here to illustrate the presence of the hardpan and to correlate with the soil water readings made in the in-row position.

Leaf samples (20 per plot) were collected at early bloom from upper mature leaves on vegetative stems each year. On 27 August, 1991 (prior to leaf shed, 119 DAP) four intact cotton plants were harvested from each plot. Harvested plants were separated into stems, leaves, and bolls. Leaf samples taken at early bloom both years and plant parts taken on 27 August 1991 were dried at 140°F (60°C). Plant parts from the intact plants were then weighed. Subsamples were ashed at 842 °F (450 °C) and digested using 1 *M* HNO_3 and 1 *M* HCL (Hue and Evans, 1986). Potassium in the digests was determined using inductively coupled argon plasma (ICAP) spectrophotometry (ICAP 9000®, Thermo Jarrell-Ash Corp. Franklin, MA).

Fresh weights were also recorded from the plant parts taken from the intact plants on 27 August 1991. Prior to drying plant parts, leaves were visually rated for K deficiency symptoms, separated by degree of deficiency, and measured for total surface area using a LI-3000 Area Meter (LI-COR® Inc., Lincoln, NE). Leaves were rated and separated according to the following scale: 1) dead; 2) severe deficiency symptoms; 3) moderate deficiency symptoms; 4) slight deficiency symptoms; and 5) healthy, with no deficiency symptoms.

All data were analyzed using general linear models (GLM) and stepwise regression procedures of SAS (SAS, 1985). Means were separated using Fisher's protected LSD at the 0.10 level of significance.

Results and Discussion

Soil penetrometer measurements taken within the row showed the presence of a well-developed hardpan and disruption of the pan by subsoiling (Fig.1). Soil strength from the 5-inch depth to the 16-inch depth ranged from 20 to 40 bars. This thick hardpan resulted in less rooting below the 8-inch depth when subsoiling was not done (Mullins et al., 1992).

Soil water in the 0- to 8-inch depth was not affected by treatments in 1990 (Fig. 2). In 1990, averaged over the 31 day period that measurements were made, subsoiling alone or with deep placement of K had the lowest soil water in the soil in the 8- to 16-inch depth. Soil water depletion was greatest in the 8- to 16-inch depth, indicating an abundance of roots at this depth. At the 8- to 16-inch depth, soil water was highest when K was applied on the soil surface. Below the depth of subsoiling (16- to 32-inch depth), soil water was lower in subsoiled treatments than in nonsubsoiled treatments. This indicates greater root growth and soil water extraction below the 16-inch depth following subsoiling.

Rainfall amount and distribution was better in 1991 than 1990. Soil water measurements were made over a longer period of time (45 days) than in 1990 and were begun prior to peak bloom, the period of maximum water use by cotton. As in 1990, soil water contents were similar among treatments at the 0- to 8-inch depth (Fig. 3). At the 8- to 16-inch depth, deep placement of K resulted in the lowest soil water content maintained during the 45 day measurement period, and surface placement of K without subsoiling maintained the highest soil water content. This indicates that deep placed K increased root growth and soil water extraction in the subsoiled zone, and that surface K application without subsoiling limited soil water extraction below the 8-inch depth. Root growth measurements not presented here showed root length density was highest in the surface soil with surface applied K and no subsoiling (Mullins et al., 1992). The same trend for soil water depletion was found at the 16- to 32-inch depth as in the 8- to 16-inch depth. Subsoiling decreased soil water in this zone, and deep placement of K maintained the lowest soil water below the 16-inch depth during the measurement period.

In 1990, the highest stomatal conductance, averaged over the measurement period, was maintained in the no-K, nonsubsoiled treatment (Table 1). This treatment was significantly higher in stomatal conductance than treatments that were subsoiled. Stomatal conductance seemed to be related to plant size, the larger plants resulting from subsoiling had the lowest stomatal conductance, but the highest seed cotton yields (Table 1). In 1991, over the course of the measurement period, stomatal conductance was highest with the no-K nonsubsoiled check, and lowest where K fertilizer was applied (Table 1). Lowest stomatal conductance was maintained in the subsoiled-surface applied K treatment. Stomatal conductance remained high and there were no indications of stress sufficient to cause stomatal closure in 1990 or 1991. Treatment effects on stomatal conductance could not be explained by soil water maintained during the measurement periods either year. Even under conditions of limited soil water, cotton stomata are reported to be relatively insensitive to closure by water stress (Jordan and Ritchie, 1971; Ackerson and Kreig, 1977; Ackerson et al., 1977).

In 1990, subsoiling without application of K resulted in the lowest leaf K concentration, and the highest leaf K concentration was found in nonsubsoiled plots with K applied to the soil surface (Table 1). Leaf K concentrations reflected the effect of applied K in raising concentrations, and the dilution effect of larger plants as a result of subsoiling. In 1991, treatment effects were similar to those in 1990, with the exception that subsoiled plots with K applied (either in the subsoil slot or on the soil surface) had the highest leaf K concentration. Regression analysis showed a slight negative linear relationship ($P \leq 0.13$, $r^2 = 0.09$) between stomatal conductance and leaf K concentration. Potassium deficiency can cause stomatal closure in plant leaves that are normal in appearance, i.e., not showing visible K deficiency symptoms (Peaslee and Moss, 1966; Hsiao, 1975). Leaf K concentrations at early bloom in both years of this study were within reported sufficiency ranges (Sabbe and Zelinski, 1990), therefore, it is not surprising that a strong relationship between leaf K concentration and stomatal conductance was not found. Even though K was sufficient and stomatal conductance was not strongly correlated to leaf K concentration, cotton showed visible leaf deficiency symptoms, especially in the subsoiled plots where K was not applied or was applied in the subsoil slot (Table 2). Since stomatal closure did not occur in our study, we cannot absolutely refute nor support the hypothesis of Combrink (1988) that stomatal closure and resultant premature leaf senescence is responsible for the characteristic leaf deficiency symptoms attributed to late season K deficiency. However, the appearance of deficiency symptoms in the absence of stomatal closure means suggests that stomatal closure is not the sole mechanism for the manifestation of symptoms. This agrees with the findings of Thimann (1985), who found that while stomatal closure accelerated leaf senescence in oat (*Avena sativa* L.) and nasturtium (*Tropaeolum majus* L.), stomatal opening was not directly linked to the prevention of leaf senescence.

Seed cotton yield was increased by subsoiling treatments in 1990, but not by any application of K (Table 1). Regression analyses showed no relationship between leaf K and seed cotton yield in 1990.

In 1991, with better rainfall distribution, subsoiling with K applied to the soil surface resulted in the highest seed cotton yields while no-subsoiling without any K application resulted in the lowest yields (Tabel 1). There was a significant linear relationship ($P<0.0001$, $r^2=0.30$) between yield and leaf K concentration at early bloom in 1991. It is interesting that subsoiling with K applied to the soil surface resulted in the highest seed cotton yield (Table 1), highest leaf K concentration (Table 1), greatest leaf area (Table 2), but lowest stomatal conductance (Table 1). Stomatal conductance was negatively linearly correlated to yield ($P<0.0008$) but the relationship was poor ($r^2 = 0.11$). Hatfield et al. (1987) reported that factors that decreased stomatal conductance of cotton had positive effects on cotton plant growth, presumably due to decreased transpiration resulting in improved water rationing from the soil profile. In our study no relationship was established by regression analysis between yield and soil water either year. In 1991, total leaf area accounted for yield variance better than any other variable ($P \leq 0.0001$, $r^2=0.40$). This is not surprising, larger plants with heavier boll loads would result in higher yields, provided plants could support the bolls. As seen in Table 1, the highest yielding treatment (subsoiled with K applied to the soil surface) had the greatest leaf area, and the highest percentage of leaf area not classified as severely K deficient or dead. Furthermore, this treatment provided the highest leaf area per boll mass (Table 2). Thus, higher yield from this treatment can be explained by the fact that this treatment resulted in the greatest photosynthetic area as well as the fact that this leaf area was a sufficient K source to support K demand by developing bolls.

Results from this study show that stomatal conductance is not well related to the appearance of late season leaf K deficiency symptoms. Results also indicate that subsoiling is necessary for maximum cotton yields on Coastal Plain soils with root-restricting hardpans. However, surface application of K fertilizer is superior to deep placement of K on these soils, even if the subsoil tests low in K. These results agree with those of Patrick et al. (1959), who found no advantage to deep placement vs. surface placement of N-P-K fertilizer to corn and cotton grown on a Gallion silt loam soil (fine-silty mixed thermic aeric Typic Hapludalfs) with a plowpan, provided the crops were all deep tilled. Our results are also supported by recent work that showed cotton roots located 12- to 24-inches deep were less effective in P uptake than roots in the surface 12 inches of soil (Nayakekorala and Taylor, 1990). Increased soil water depletion within subsoiled and deeper zones from deep placed K could possibly even deplete water in the profile at a faster rate, resulting in a reduced period of soil water availability to the plant in an extended drought on these soils.

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Table 1. Seed cotton yield, leaf K concentration at early bloom, and stomatal conductance of cotton as affected by subsoiling and K placement.

Treatment	Yield (lb/acre)	Leaf K (%)	Stomatal Conductance* (cm/s)
		1990	
no-K, not subsoiled	2140	1.60	1.23
no-K, subsoiled	2785	1.49	1.08
K surface-applied, not subsoiled	2099	2.07	1.12
K surface-applied, subsoiled	2760	1.89	1.02
K deep-placed, subsoiled	2736	1.72	1.02
$LSD_{0.10}$	489	0.228	0.135
		1991	
no-K, not subsoiled	2589	1.37	2.02
no-K, subsoiled	2859	1.30	1.66
K surface-applied, not subsoiled	3079	1.68	1.51
K surface-applied, subsoiled	3398	1.90	1.02
K deep-placed, subsoiled	2932	1.83	1.26
$LSD_{0.10}$	457	0.346	0.143

*Average stomatal conductance measured on three days during 116 to 134 days after planting (DAP) in 1990 and six times during 96 to 135 DAP in 1991.

Table 2. Leaf area by K deficiency severity and leaf area per fresh boll weight as affected by subsoiling and K fertilizer placement.

Treatment	Leaf Area						
	H	Sl	M	Sv	D	Total	LA/boll
	--------cm²/plant--------						--cm²/g--
no-K, not subsoiled	57	152	303	298	39	849	10.2
no-K, subsoiled	86	165	289	638	121	1298	11
K surface-applied, not subsoiled	22	185	377	285	68	937	12.4
K surface-applied, subsoiled	144	443	774	537	112	2011	14.8
K deep-placed, subsoiled	30	166	386	516	182	1281	10.1
$LSD_{0.10}$		142	193	252	ns	469	2.81

K deficiency symptom rating: H=healthy, Sl=slight, M=moderate, Sv=severe, D=dead.

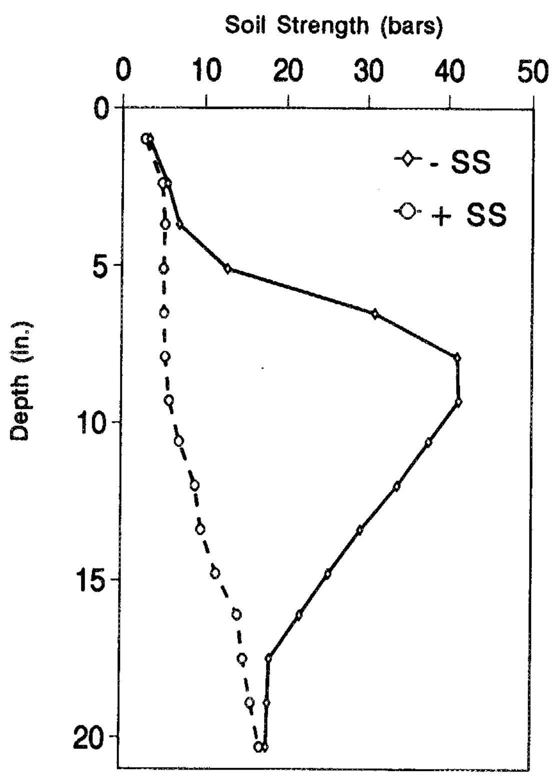

Figure 1. Soil strength under the row of cotton as affected by subsoiling in 1991.

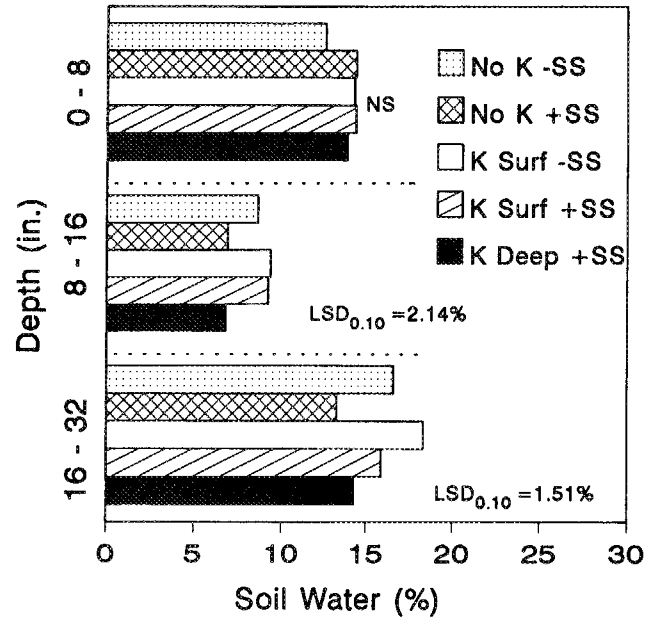

Figure 2. Soil water maintained under the row of cotton during period 113 to 134 days after planting as affected by subsoiling and K fertilizer in 1990.

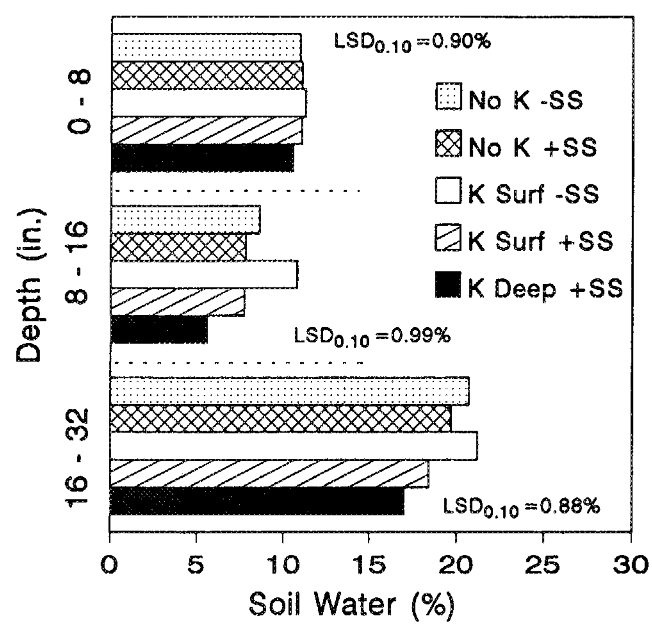

Figure 3. Soil water maintained under the row of cotton during period 90 to 135 days after planting as affected by subsoiling and K fertilizer placement in 1991.